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Effects of Water Stress at Different Growth Stages on Processing Pepper (*Capsicum annum* Cv. *Kapija*) Yield Water Use and Quality Characteristics

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Abstract: This study was conducted to investigate the effect of water stress at different growth stages on processing pepper yield water use and quality characteristics at Büyük Menderes Plain in Turkey. The experiment was set up in Randomized Block Design with six treatments and three replications during the years of 2001 and 2002. In the trials irrigation treatments employed single water stress at flowering, fruit formation, yellow fruit formation, beginning of the red ripening and ripening stages. Results of this two years study shows that different irrigation treatments significantly affected yield and quality parameters. The highest irrigation water was applied to the full irrigation (T_1– 100%) treatment. The highest pepper yield was obtained from full irrigation (T_1–100%) treatment. Irrigation Water Use Efficiency (IWUE) and Water Use Efficiency (WUE) were varied from 4.13-6.66 to 3.15-5.12 kg/da-mm, respectively for treatments. The period most sensitive to water stress was flowering stage. The yield response factor (k_y) was found to be 1.14 for the total growing season.

Key words: Processing pepper (*Capsicum annum* Cv. *Kapija*), water stress, growth stages, water use

INTRODUCTION

Peppers are important for the production of pasta and of spice as well as the fresh vegetable, directly consumed. Forty six percent of production is obtained from Asia, with 7,6 million ton China the principal producing country. After the Mexico, Turkey is the third most important producing region of fresh pepper with 1.4 million ton[1]. In Büyük Menderes Plain, fresh pepper production is about 58.000 metric tons per year from 3% of irrigated area. Processing pepper also is produced nearly 10.000 metric tons per year from this region[2].

Pepper is very sensitive to limited and excessive soil water supply in root zone. For high yield, an adequate water supply is required during the total growing period. The period at the beginning of the flowering stage is most sensitive to water shortage. While maximum yields were obtained with full irrigation, almost maximum yield generally were obtained when irrigation was made to provide adequate water during flowering and fruit formation periods[3-5]. Therefore, irrigation scheduling and management of processing peppers are essential in semi-arid regions, like Büyük Menderes Plain in Turkey. On the other hand, limited availability of irrigation water requires certain changes in irrigation management. Generally, applicable procedure is to evaluate the benefits of changing irrigation water management based on water stress on specific growth stages [6-8].

In order to implement water deficit successfully, specific growth stages of the processing pepper at which they can overcome water stress with no significant effect on yield need to be well defined[3,5,9-11]. Therefore, it will be possible to develop optimum deficit irrigation programme for processing pepper under semi-arid climate conditions.

The objective of this study was to analyze the effect of water stress at different specific growth stages on processing pepper yield, water use and quality parameters. Also, the relationship between water use and pepper yield and yield response factor of processing pepper in the research area were evaluated.

MATERIALS AND METHODS

The experiments were conducted during the growing seasons of 2001-2002 at the Agricultural Research Station of Adnan Menderes University, Aydin, Turkey. The altitude, latitude and longitude of the experimental site are 56 m, 37° 51' N and 27° 51' E, respectively.

The experiment site has rainy and warm winters and dry and hot summers. Some climatologic monthly data of growing season for the experimental site were summarized in Table 1. The average of annual temperature, relative

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Table 1: Some climatic data for the experimental years

Months	Average temperature (°C)	Average relative humidity (%)	Average wind speed (m/s)	Average sunshine duration (h)
2001				
May	21.5	56.1	1.3	8.6
June	26.8	41.2	1.8	11.4
July	30.2	42.9	1.8	11.5
August	29.1	53.8	1.5	10.9
September	24.3	54.2	1.6	9.5
2002				
May	21.5	63.0	1.7	10.8
June	27.2	52.7	1.7	11.2
July	28.5	58.2	1.7	10.9
August	27.7	58.3	1.7	10.7
September	22.8	68.2	1.5	7.8

Table 2: Some physical characteristics of soils at the experimental site

Soil depth (cm)	Soil texture	Bulk density (g/cm^3)	Field capacity (%)	Wilting point (%)	Available water holding capacity (mm)
0-30	Loam	1.61	23.1	6.1	82.0
30-60	Loam	1.45	22.9	5.8	74.4
60-90	Sandy-loam	1.52	18.4	7.3	50.7
0-90					207.1

Table 3: Irrigation treatments

	Growth periods				
Treatments	Flowering	Fruit formation	Yellow fruit formation	Beginning of red ripening	Ripening
T_1	+	+	+	+	+
T_2	+	+	+	+	-
T_3	+	+	+	-	+
T_4	+	+	-	+	+
T_5	+	-	+	+	+
T_6	-	+	+	+	+

- No irrigation (0%), + Full irrigation (100%)

humidity, wind speed, sunshine duration and total annual precipitation are 17.5 °C, 63%, 1.6 m/s, 7.6 h and 657.7 mm respectively[12].

The soil of the experimental area was found loam and sandy loam in texture. Some physical characteristics of soils at the experimental site are presented in Table 2. The irrigation water quality was C_2S_1.

Seedlings of processing pepper (*Capsicum annum* Cv. *Kapija*) were selected for this study. Seedlings were planted on 10 May 2001 and 19 May 2002 . The last harvest dates were September 15, 2001 and September 25, 2002. A row spacing of 0.70 m and within row spacing of 0.40 m were used. There were 75 plants in each plot. At seedlings of pepper planting, the plot sizes 3.5x6.0 m (21.0 m^2), whereas the basic plot sizes harvested were 2.1x5.2 m (10.92 m^2). There was a 3 m space between each plot in order to prevent water movements among the treatments. According to soil fertility analysis, 150 kg ha^{-1} N, 50 kg ha^{-1} P_2O_5 and 50 kg ha^{-1} K_2O were applied.

The experiments were set up in complete randomized block design consisting of six treatments and three replications. Water application stages were determined according to Doorenbos and Kassam's[3] approximation. Therefore, to investigate the effect of water stress, five different growth stages were identified as flowering, fruit formation, yellow fruit formation, beginning of red ripening and red ripening stages (Table 3).

Soil moisture content in the plots was determined gravimetrically in the soil layers 0-30, 30-60 and 60-90 cm during the whole growing season. The amount of soil water in the 0.60 m top layer was used to initiate irrigation. All the experimental treatments were irrigated at the same time as the T_1 treatment, being watered at each growth period with the amount of irrigation water required to fill the 0-60 cm soil depth to field capacity. Other treatments were irrigated similarly except for omitting the irrigation application at a specific growth stage. Irrigation water was applied with ponded furrow irrigation and total water to each plot was measured with a flow meter.

The water balance equation was used in order to determine seasonal evapotranspiration for all the treatments[13]. Water use efficiencies were calculated based on total depth of irrigation water (IWUE) and seasonal evapotranspiration (WUE)[14].

In order to evaluate sensitivity of growth stages to water stress, yield response factor k_y defined as the ratio of relative yield decrease to relative evapotranspiration deficit, was calculated from the actual yield, the maximum yield, the actual evapotranspiration and the maximum evapotranspiration[3].

Peppers were harvested by hand in two pickings after removing border effects. Plant height was measured before harvesting from all plots using 5 randomly selected crops. After pepper was harvested, processing pepper yields were determined for each plot. Also, 10 fruits were selected randomly for quality analysis from each replicate plots. First, the parameters of fruit (skin thickness, weight and length) were measured and averaged. After, those fruits were cut and fruit juice were obtained. Soluble solids, pH and color were determined from this juice[11,15,16].

Data were analyzed seasonally by analysis of variance and relationship between water use and pepper yield were evaluated using regression analysis.

RESULTS AND DISCUSSION

Various growth stages of pepper have affected the amount of irrigation water applied to treatments. In the full irrigation treatment (T_1), the amount of irrigation water was 669 and 629 mm in 2001 and 2002, respectively (Table 4).

Table 4: Evapotranspiration and water use results of processing pepper according to the treatments and years

Year	Treatments	Irrigation water applied (mm)	Soil water depletion (mm)	Seasonal ET (mm)	Water use efficiency (kg/da-mm)	Irrigation water use efficiency(kg/da-mm)
2001	T_1	669	149	818	3.67	4.49
	T_2	481	138	619	4.04	5.20
	T_3	502	176	678	3.32	4.48
	T_4	482	146	628	3.41	4.45
	T_5	511	136	647	3.26	4.13
	T_6	532	111	643	3.15	3.81
2002	T_1	629	71	700	4.65	5.19
	T_2	454	91	545	5.12	6.66
	T_3	474	81	555	4.68	5.48
	T_4	460	70	530	4.58	5.28
	T_5	494	62	556	4.34	4.88
	T_6	510	67	577	4.08	4.60

Table 5: Yield, vegetative growth and quality parameters of processing pepper according to the treatments and years

Year	Treatments (mm)	Total yield (kg/da)	Plant height (cm)	Fruit length (cm)	Fruit skin thickness (mm)	Fruit weight (g)	Total soluble solids (%)	Fruit color	pH (a/b)
2001	T_1	3006a**	74.5a**	9.9ns	4.31ab*	37.53a*	9.13ns	2.38ns	5.08ns
	T_2	2504b	74.2a	9.3	4.35a	29.97b	9.60	2.36	5.23
	T_3	2252bc	69.3b	9.0	3.88bcd	31.24ab	9.46	2.31	5.24
	T_4	2146c	65.4bc	8.9	4.11abc	27.2b	9.53	2.37	5.15
	T_5	2110c	63.7c	8.7	3.75cd	26.41b	9.26	2.33	5.11
	T_6	2025c	69.0b	8.6	3.56d	29.01b	10.0	2.35	5.03
2002	T_1	3255a**	77.0a**	13.9a**	4.44a*	41.22a**	8.80ns	2.28ns	5.23ns
	T_2	2794b	76.3a	12.3b	4.08ab	37.7b	9.33	2.07	5.35
	T_3	2600bc	70.3b	11.6bc	3.30c	36.89b	9.53	2.10	5.27
	T_4	2430cd	65.6c	11.2bc	3.52bc	35.72b	9.33	2.08	5.33
	T_5	2414cd	68.6bc	11.5bc	3.50bc	37.61b	9.0	2.35	5.26
	T_6	2349d	65.1c	10.2d	3.51bc	26.96c	9.66	2.12	5.29

*, ** Significant at the 0.05 and 0.01 level, respectively, ns: non-significant

Table 6: Relative yield decrease and relative evapotranspiration deficit for total growing period

Year	Treatments	Y_m (kg/da)	Y_a (kg/da)	Et_m (mm)	Et_a (mm)	$1-(Y_a/Y_m)$	$1-(ET_a/ET_m)$	k_y
2001	T_1	3006		818				
	T_2		2504		619	0.16	0.24	0.67
	T_3		2252		678	0.25	0.17	1.47
	T_4		2146		628	0.28	0.23	1.21
	T_5		2110		647	0.29	0.20	1.45
	T_6		2025		643	0.32	0.21	1.52
2002	T_1	3255		700				
	T_2		2794		545	0.14	0.22	0.63
	T_3		2600		555	0.20	0.20	1.00
	T_4		2430		530	0.25	0.24	1.04
	T_5		2414		556	0.26	0.20	1.30
	T_6		2349		577	0.28	0.17	1.64

Seasonal ET values during two years varied from 530 to 818 mm. The highest evapotranspiration was obtained from T_1 as 818 and 700 mm for 2001 and 2002, respectively. Other treatments underwent water deficit and gave lower seasonal ET. Evapotranspiration increased with increased amount of irrigation water applied to the treatments (Table 4). During the first year, irrigation water and ET values were higher than that of second year (2002). This may be attributed to the different climatic conditions of the years such as temperature, relative humidity and different growing season length. Seasonal ET and water amounts applied to the adequate irrigation treatment (T_1) in both years are in agreement with other researchers[9,11,17-21].

As shown in Table 5 data obtained from the two year study showed that fruit yield was significantly ($p<0.01$) affected by irrigation treatments. Fruit yields ranged from 2025 to 3255 kg/da in both years. The highest and lowest fruit yield were obtained from T_1 and T_6 respectively. As can be seen from Table 5, T_1 and T_2 provided the highest fruit yield group. On the other hand, the lowest yield group was comprised of T_6. According to individual growth stages, the highest decrease was obtained from the flowering period T_6 and this decrease was 32% in 2001 and 28% in 2002. These results shows that, the fruit yield is most sensitive to water stress at flowering stage. The fruit formation stage was also sensitive to water stress. Similar effects of irrigation on pepper growth stages have also been reported by Katerji *et al.*[5], Leon and Manftalvo[9].

The relationships between seasonal ET and fruit yield have been evaluated for each experimental year (Fig. 1, Table 4 and 5). Results of the regression statistical

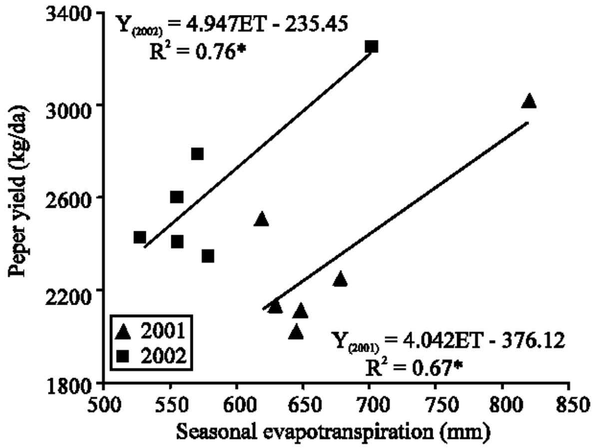

Fig. 1: Relationship between pepper yield and seasonal evapotranspiration

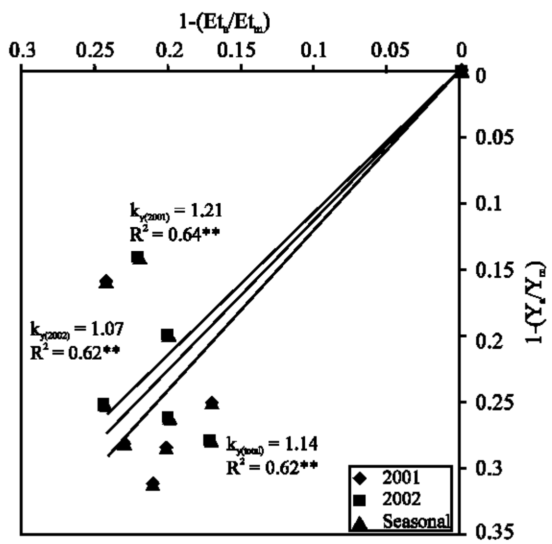

Fig. 2: Relationship between relative evapotranspiration deficit and relative yield decrease

analysis showed that close relationship exist between seasonal ET and fruit yield ($p<0.05$). For each experimental year similar linear relationship was also observed by Ersöz and Avci[11].

The Irrigation Water Use Efficiency (IWUE) of the treatments were higher than total Water Use Efficiencies (WUE) for both years (Table 4) because water consumption was higher than the amount of irrigation water applied. WUE varied between 3.15 -5.12 kg/da-mm for treatments in both years. Using this values, the highest WUE was obtained in T_2 with 4.04 kg/da-mm in 2001 and 5.12 kg/da-mm in 2002. Both of the water use efficiency values decreased when the water stress was applied at the flowering and fruit formation stages. Under water stress conditions similar results for pepper have been mentioned by the many researchers [4,10,21-24].

The influence of irrigation treatment on the plant height and fruit length were highest for treatment T_1 in both years (Table 5). Statistically significant differences ($p<0.01$) were found between the treatments for each year. On the other hand, there was no significant difference in fruit length during the first year, however, a significant difference ($p<0.01$) was found in second year. There were also significant ($p<0.05$) irrigation treatment effects for both the fruit skin thickness and fruit weight. The fruit weight for treatment ranged from 26.41 g (T_5) to 37.53 g (T_1) in first year and 26.96 g (T_6) to 41.22 g (T_1) in second year. These results are in accordance with those of Ersöz and Avci[11], Üstün[25] and Yildirim *et al.*[26]. While evaluating the yield quality parameters, total soluble solids, fruit color and pH were not significantly affected by irrigation treatments. The total soluble solid was lowest for the full irrigation (T_1), (9.13% in 2001 and 8.80% in 2002). Depending on the growth stages, increasing amount of water decreased total soluble solids. This was also stated by Pellitero *et al.*[10], Beese *et al.*[22] and Sanders *et al.*[27].

The response of pepper yield to water supply can be quantified through the yield response factor (k_y) which relates relative yield decrease to relative evapotranspiration deficit. The slope of the fitted regressions (Fig. 2 and Table 6) represents the yield response factor (k_y). Values of k_y for a given crop and locality varied from year to year. From the slope of the curves plotted on the Fig. 2, the highest yield reduction due to water stress (highest value of k_y = 1.21) occurred during the 2001 growing season. On the other hand, value of k_y was lower (1.07) for the second year. The average yield response factor was k_y = 1.14 determined from our study is consistent with 1.10 determined by Doorenbos and Kassam[3]. Average k_y value of 1.14 is higher than that of 0.62 pointed out by Ersöz and Avci[11] for the coastal part of Black Sea. This disagreement could be explained by the high relative humidity and different precipitation characteristics of the coastal areas.

According to the results obtained from this study, it can be said that the processing pepper is sensitive to the deficiency of the moisture level in the root zone. The highest average (3006 kg da^{-1} in 2001 and 3255 kg da^{-1} in 2002) pepper yield (3130.5 kg da^{-1}) was obtained from the full irrigation (T_1). The average water requirement of pepper was obtained as 759 mm. Statistically significant difference and a linear relationship between the pepper yield and water consumption were determined. In order to obtain a maximum pepper yield, crop water requirement should be met during the whole growth stages (T_1).

However, under irrigation water limitation, the flowering stage of processing pepper should be given priority for irrigation followed by fruit formation. Therefore, under this conditions, when water stress applied to flowering and fruit formation stages, (T_6 and T_5) average (32% in 2001 and 28% in 2002 for T_6, 29% in 2001 and 26% in 2002 for T_5) pepper yield decrease were 30 and 28%, respectively.

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